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Development Status of Accident Tolerant Fuel Cladding for LWRs

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1. Introduction

We have been developing accident tolerant fuel (ATF) after Fukushima accident for the last 6 years worldwide. Regarding the ATF cladding, various ideas have been introduced at the beginning, but recently, a few concepts have been converged in considering of economic efficiency, fabrication and performance [1-5]. The ATF cladding has been selected as a concept capable of shirt term R&D rather than long-term R&D considering the operational life (~ 60 years) of the light water reactors (LWRs) and the development cycle (~25 years) of the cladding tube. ATF cladding should also consider safety and performances in the entire fuel cycle (manufacturing to storage) as well as stability in an accident environment. This suggests that it is difficult to apply it as a nuclear fuel cladding because it has one or two good characteristics in an accident environment. About 6 year studying for ATF cladding, the concept of coating on zirconium cladding tubes is underway in Westinghouse, Framatome, and Korea for pressured water reactors (PWRs), and the concept for applying FeCrAl-based alloys is underway in GE for application to boiling water reactors (BWRs). In this paper, we present the current state of ATF cladding for LWRs and the problems to be solved for successful development.

2. Development status of ATF cladding

Table I: Various concepts for ATF cladding development

Lead Organization	Category – Major Technology Area	Team Members
AREVA	Protective materials, MAX phase, Coated Zr cladding, SiC/SiC composites	U. Wisconsin, U, Florida, SRNL,TVA, Duke
Westinghouse	Cladding coating (near) SiC cladding (mid)	General Atomics, MIT, EWI, INL, LANL,TAMU, Southern Nuclear Operating Company
General Electric Global Research	Advanced steels for cladding	Global Nuclear Fuels, LANL, U. Michigan
University of Illinois	Modified Zr-based cladding	U. Michigan, U. Florida, INL, U. Manchester, ATI Wah Chang
University of Tennessee	Ceramic Coatings for Clad	Penn State, U. Michigan, UC Boulder, LANL, Westinghouse, Oxford, U. Manchester, U. Sheffield, U. Huddersfield, ANSTO
INL	Zr liner + SiC hybrid	
EPRI	Zr-Mo alloy	EPRI, INL, GE
HRP	CrN phase coating	-
KAERI	Surface modified cladding Metal-ceramic hybrid cladding SiC cladding	-

Table 1 shows the various concepts for developing ATF cladding. The performance requirements to be solved by ATF cladding at the beginning of development were high temperature oxidation resistance and high temperature strength. Although, cladding tube satisfies high temperature oxidation and high temperature strength, it has limitations to apply it as a nuclear fuel cladding tube through many years of search. At present, ATF cladding is converged into two concepts. Coated cladding was selected from Westinghouse, FRAMATOME, and KHNP for PWRs and FeCrAl alloy was selected from GE for BWRs based on the test data.

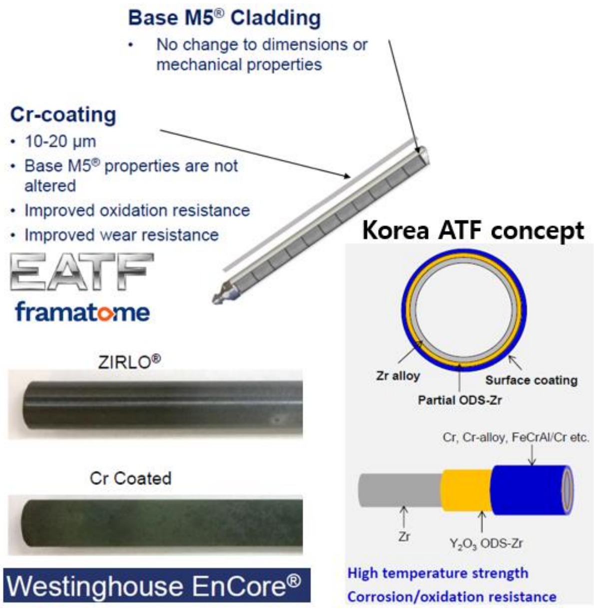

Fig. 1. Coated cladding concepts of Framatome, Westinghouse, and Korea ATF.

Coating materials used in coated cladding concept are Cr or CrAl alloys, which have excellent oxidation resistance at high temperatures and have no significant problems in neutron economics [3-5]. Physical vapor deposition (PVD), arc ion plating (ARC) and cold spray (CS) processes are being developed as coating methods. Therefore, it was known that the adhesive strength to the coated cladding was evaluated to be excellent in normal and accident conditions. The coated cladding, developed by Framatome and Westinghouse, has its own brand of EATF and EnCore, respectively, and is preparing for commercial reactor testing as shown in Fig.1. Coated cladding in Korea is under commercial development by linking KHNP, KAERI and KNF. FeCrAl alloy cladding is being prepared by GE and ORNL for a BWR testing.

Important points in the development of Fe-based alloys should be solved such as high neutron absorption cross-sectional area, tritium permeation, low melting point and weight loss in PWR environment. In addition, there is a very shortage of out-of-pile and in-pile data for licensing. The reason why different materials are applied in BWR and PWR is that the manufacturability and performances of the material are compatible with the water chemistry and operating conditions of the reactor. These ATF cladding were subjected to manufacturing, out-of-pile test, in-pile test in test reactor, and code-related studies.

3. Consideration items to develop ATF cladding

Important points in cladding development are full cycle applicability and economics from manufacture to storage. In order to develop a new cladding, it is necessary to build commercial facilities related to manufacturing. Since it is very expensive and time-consuming to construct commercial facilities, it is most economical to utilize existing manufacturing facilities. The cost of cladding, considering material costs and manufacturing equipment, is also an important consideration. In addition, an important issue in the development of new cladding is the acquisition of licenses. For example, zirconium cladding tubes are at least 97% Zr, and even if the composition changes from 0.1 to 1%, the data and performance codes, including commercial reactor tests, must be prepared again. In normal operation conditions, the major requirements, such as corrosion, creep, irradiation growth, and wear, generally are satisfied using new alloy cladding. In accident conditions, various issues, such as high-temperature oxidation, ballooning and burst, and low ductility after accidents, will be solved using new alloy cladding. In addition, the tested cladding in commercial reactor should be examined by post irradiation examination (PIE), and it will be used to expect for transport and storage problems. Because of this costly and time-consuming development process, coatings on existing Zr alloys with fast development methods are preferred for ATF development.

3. Conclusions

As an ATF cladding development, coated cladding tubes are being developed in Framatome, Westinghouse, and Korea for PWR, whereas FeCrAl cladding tubes are being developed in GE and ORNL for BWR. The cladding material was selected considering the assembly design and the operating condition of commercial reactor types. These ATF cladding were subjected to manufacturing, out-of pile test, in-pile test in test reactor, and code-related studies. To develop fast ATF cladding technology, these cladding are being invested heavily in commercial reactor tests and license codes.

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